Design of 100 MW LNG Floating Barge Power Plant

I Made Ariana[1], Hari Prastowo[2], Aldio Paruna[3]

***Abstract*—floating barge power plant able to supply amount of electricity to undeveloped island in Indonesia. In this research, the generator will be use in the power plant is dual-fuel engine. The process was determine the engine and every equipment along with its configuration then arrange the equipment. The result, MAN18V51/60DF selected along with its system configuration and its general arrangement. The final design enable 7.06 days of operation with daily average load (64.76 MW) or 4.57 days with continues 100 MW load. In the end, the mobile power plant can be built on Damen B32SPo9832 Barge and comply with the regulation.**

Keywords—diesel engine, fuel gas, fuel oil, gas turbine, LNG, mobile power plant

I. Introduction

Indonesia is the largest archipelago where it consists more than 17,000 islands scattered in an area of 1,904,569 km^2. The archipelago conditions complicate the development of many aspects and creates a condition where several islands in Indonesia are not evenly. Several East Indonesia Islands have peak load exceed the capacity of PLN installed power plant. [1]

There are a plans to construct an onshore power plant in several area such as NTB (Lombok), South Sulawesi (Punagaya), and South Sulawesi (Malea) [1]. Power barge may become a solution to bridge the gap for local demand of power until certain of time. Floating power plant can be built faster than onshore power plant since it can be construct in well-developed area.

Fossil fuel are highly consumed to produce energy but emission substance like CO_2, NO_x and SO_x discharged by fossil fuel are produced in significant amount. Associated with the regulation a ship built after 1 January 2016 must comply with pollution regulation, therefore to meet the new standard, LNG fuel is considered due to its level of cleanliness compared to other fossil fuel. [2]

II. Design Criteria

To develop the power plant and to achieve the satisfying result, a proper criteria and analysis are required. Several design criteria are determined in order to meet the requirements. The design criteria is as below;

A. Engine Criteria

The parameter to choose the engine in this project are engine's maximum power output, dimension, weight, and fuel consumption.

All of the engine criteria are related, for example, an engine with small power will has less weight and smaller dimension, but to achieve 100 MW it will require several engines which may lead to higher total weight and space.

B. Choosing the Engine

To determine the engine, the aspects are being compared. The determination process done for two type of engine which is diesel engine and gas turbine.

- **Diesel Engine**

Based on the calculation with 94.3% (assumed typical losses is 5.7% in transformer, frequency converter, and alternator) [3] of engine efficiency to produce electricity. The load rate, fuel consumption of the engine when it's arranged as multi-engine plant is as Table 1.

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TABLE 1.
REQUIRED DIESEL AND LOAD RATE FOR 100 MW ELECTRICITY

Engine	BHPmcr [kW]	Engine Required	Load Rate [%]	Total Weight [t]
MaK 16VM46DF	15,440	8 Engine	85.85	1,760
Wartsila 16V46DF	18,320	7 Engine	82.69	1,645
Wartsila 18V50DF	17,550	7 Engine	86.32	1,708
MAN 18V51/60DF	18,000	7 Engine	84.16	1,855

To determine the specific gas fuel consumption (SGFC) and specific fuel oil consumption (SFOC) can be done by extrapolating the available data in the project guide since the available data from the project guide is limited [4]. Figure 1 shows the example of extrapolation result while the result of SFOC, SGFC, and fuel consumption can be seen in Table 2.

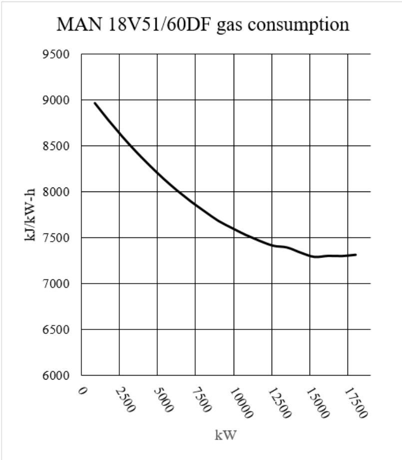

Figure. 1. Extrapolation of specific fuel consumption

TABLE 2.
VARIOUS DIESEL ENGINE LNG AND OIL CONSUMPTION

Engine	LNG Cons. $[m^3/day]$	Oil Cons. $[m^3/day]$	SFOC $[g/kWh]$	SGFC $[kJ/kWh]$
MaK 16VM46DF	843.32	3.70	1.29	7,407.30
Wartsila 16V46DF	846.02	2.90	1.02	7,431.03
Wartsila 18V50DF	841.21	3.50	1.22	7,388.78
MAN 18V51/60DF	833.26	6.96	2.43	7,318.98

To convert the measurement unit of natural gas from energy unit into volume unit can be done by using formula (1) [5];

$$Vng\ [m^3] = NG\ consumption\ [kJ] \times 26.84 \left[m^3/_{kJ}\right] \times 10^{-6} \quad (1)$$

The result from the formula which is volume in gas phase can be converted to volume in liquid phase by multiply the result with $\frac{1}{600}$ [6], it can be concluded that the volume of liquefied natural gas is 600 smaller than when it is in its gas phase.

- **Gas Turbine**

The load rate of the engine when it's arranged as multi-engine plant, fuel consumption and total weight to produce 100 MW of electricity are as Table 3; Due to limited data associated with the specific fuel consumption at several loads, SGFC at base load were used to calculate the fuel consumption, the result are as Table 4 where formula (1) used to convert the formula's result.

Based on the result, the next process to develop Conceptual Design of 100 MW LNG Mobile Power Plant will be use MAN 18V 51/60DF as the engine with gas fuel consumption.

TABLE 3.
REQUIRED GAS TURBINE AND LOAD RATE FOR 100 MW ELECTRICITY

Engine	Peak Load [kW]	Engine Required	Load Rate [%]	Total Weight [t]
GE HD6B.03	37,536	3 Engine	75.76	300
GE TM2500	26,190	4 Engine	85.81	244

TABLE 4.
VARIOUS GAS TURBINE LNG AND OIL CONSUMPTION

Engine	LNG Cons. $[m^3/day]$	Oil Cons. $[m^3/day]$	SFOC $[g/kWh]$	SGFC $[kJ/kWh]$
GE HD6B.03	1,153.05	-	-	10,740[1]
GE TM2500	1,111.82	-	-	10,356[2]

1. Based on GE Power Play Insight PowerGen Tools
2. Based on data from PT.PP for MPP PLTG Lombok

C. Barge Criteria

The power plant will be built using an existing barge to minimalize error and failure during design process [14]. Damen Stan Pontoon B32 SPo9832 which shown by Figure 2 with specification as Table 5 considered as the proper vessel to be installed and develop the design with the selected engine along with its supporting system.

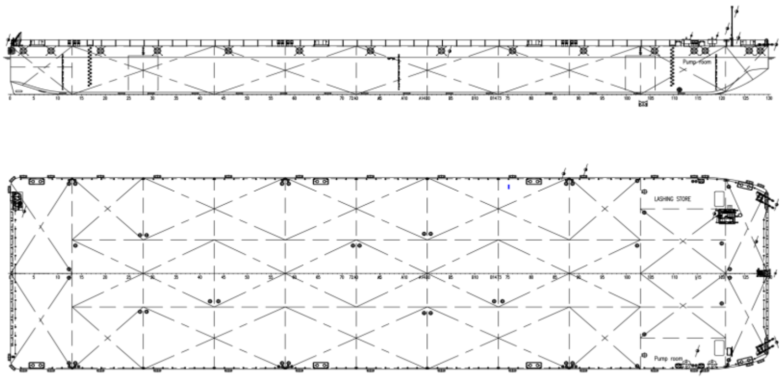

Figure. 2. Damen stan pontoon draft [7]

TABLE 5.
DAMEN STAN PONTOON DIMENSION [7]

Damen Stan-Pontoon B32 SPo9832		
	Dimension	
Length	97.5	m
Beam	32.2	m
Draft	6.2	m
Height	8.1	m

III. SYSTEM DESIGN AND DRAWINGS

Supporting system is a system that may support the engine operation where it consists various processing equipment. There are several design considerations to improve the reliability of the system.

All of the selected equipment will be arranged into a general arrangement without neglecting stability and buoyancy aspects.

3.1 Engine and System Cluster

Engine system cluster is an arrangement which divide engine's supporting systems in order to increase its reliability rather than use single system to supply all of the engines. The plan is to divide the engines into 4 cluster where cluster 1, 2, and 3 consists of 2 diesel engines and cluster 4 consist of single engine. Every cluster has their own supply or supporting, each system will be explained further.

Lube oil supply system for every engine is independent. The requirements to have independent lube oil system for each engine are not limiting cluster system practice because the lube oil system can be connected at the lube oil treatment phase and still has an independent system for lube oil supply system. The configuration is to connect each supply system into one purifier that may covers the demand of 2 diesel engines.

The floating barge power plant use closed-circuit cooling system where most of the cooling done by fresh water (low temperature circuit and high temperature circuit) and the circuit will be cooled by sea water. Each cluster has their own closed-circuit cooling system but connected into one open-circuit sea water cooling system, therefore, a large heat exchangers are required to dissipate heat from every cluster to the sea water.

The only system arranged without cluster system is starting air system. In the operation, every activity that requires pressurized air such as engine starting, jet assist, and emergency start are connected to this system. The pressurized air is not limited in engine operation since the engine are not consume pressurized air frequently.

3.2 Fuel Supply and Treatment System

Fuel supply are very essentials to the operation. Since the chosen engine is dual-fuel engine, 2 fuel supply system which is natural gas fuel and liquid fuel system shall be designed. The following text will explain the systems;

1. Liquid Fuel Supply System

   Dual-fuel engine requires a liquid fuel supply as a pilot-fuel during its operation and fully relied on liquid fuel during liquid fuel operation mode or low-load operation of the engine such as stand-by, starting, and before the engine shut-down. The liquid fuel supply to the engine are using the cluster system while the source of this system comes from one treatment system. The fuel supply system illustrated by Figure 3 and the fuel treatment system illustrated by Figure 4.

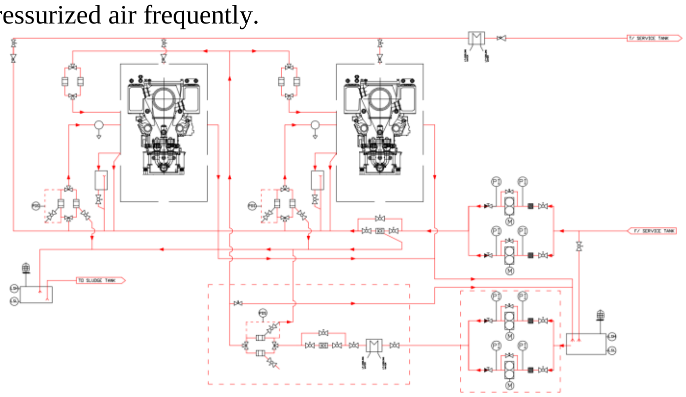

Figure. 3. Example of liquid fuel supply system

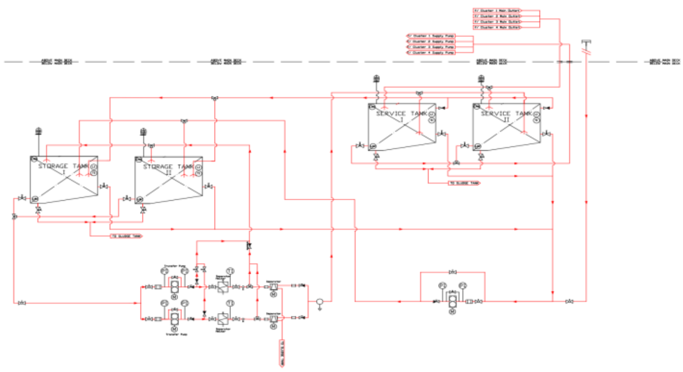

Figure. 4. Example of liquid fuel treatment system

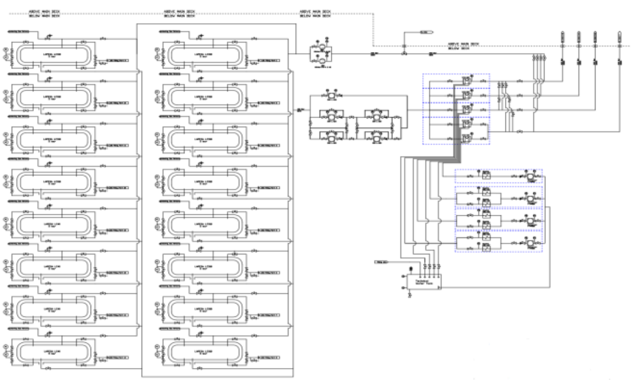

Figure. 5. LNG treatment system

3. Gas Fuel Supply System

Gas fuel supply system are divided into 2 category where there are LNG making-up system and engine supply system. Both system has different roles.

LNG making-up system convert the phase of natural gas from liquid into gas. The conversion process done by adding heat to the LNG where the source of the heat comes from exhaust gas economizer. Such system called as Intermediate Fluid Vaporizer (IFV) because the presence of a heating medium to transfer the heat from the source to the LNG where all of the heat exchanging process may done in shell and tube heat exchanger [8]. The use of IFV with Water/Ethylene Glycol (WEG) fluid as heat media considered to have lower capital cost to be used in a system [9]

To supply the vaporizer with LNG, 3 configurations of LP-Pump are used. A configuration with single pump is used when the plant need to be operated at high load while the second configuration is to supply LNG when the load is low. The third configuration, which identical to the second configuration working as a stand-by and to creates a redundant system. Complete and detail LNG making-up system can be seen in Figure 5. The gas fuel supply system is the next system configuration to distribute the natural gas. Based on Figure 5 The products of the treatment system is natural gas, based where the ends of the system has 4 flowline where each line will supply their own cluster. Each natural gas flowline goes up to the main deck and has 2 branches, except for cluster 4.

The natural gas flowline goes through gas valve unit in order to achieve proper pressure before being injected to the engine. Each engine shall has independent gas valve unit where the gas valve unit must be located in different ventilated compartment to comply with the regulation and connected with inert gas system. The system configuration can be seen in Figure 6.

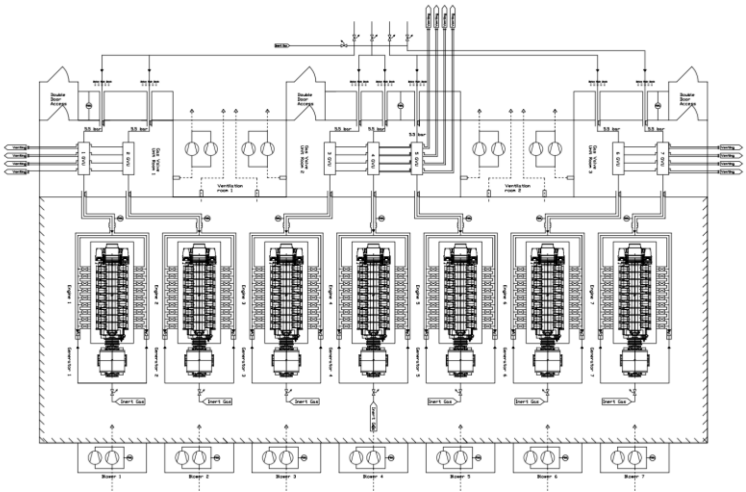

Figure. 6. Gas fuel supply system

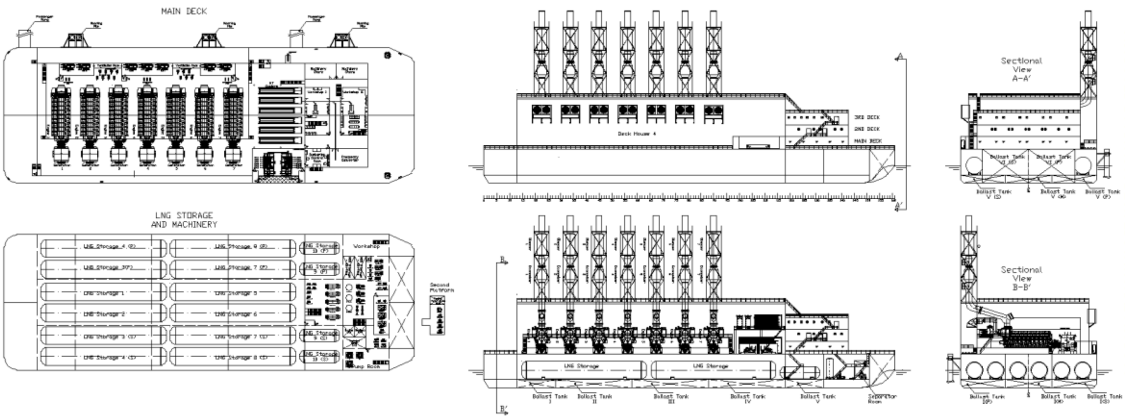

Figure. 7. 2-Dimensional general arrangement

3.3 Design Layout and Arrangement

All of the chosen equipment like processing equipment, tanks, and storages shall be arranged properly to enhance ergonomic, safety, and compliance with the regulation. Since the power plant will be built on a barge, the available space are limited, therefore, a proper arrangement should be done to maximize the utilization of available space. There are several specific layouts will be discussed in this chapter and one general arrangement.

1. LNG Storage

The fuel storage calculation process is done by choosing several type of type C pressurized vessels that available on the market. The storages were combination of 12 tanks of LAPESA 4200 H type LC318 and 4 tanks of LAPESA 3000H type LC40 [10]. The arrangement of this tanks develop a design with 3811.27 m^3 of LNG as maximum capacity. The layout of LNG tanks can be seen in Figure 7 where the figure illustrates 2-dimensional general arrangement of the floating barge power plant from several views along with the LNG tanks, equipment, plants, and structure arrangement.

2. Diesel Oil Storage

Diesel oil is required to support the combustion process where the diesel oil act as a pilot fuel. The total capacity of the storage is 45.05 m^3 of MDO type DMB. The layout of the diesel oil storage can be seen in Figure 7. The actual volume of the tank is exceeding the requirement of the plant to enable low-load operation such as engine starting and stand-by which operated using only liquid fuel.

Based on the arrangement, tanks for diesel oil are separated into 2 types where the first type act as the storage while the second type act as a service tank.

3. General Arrangement

All of the chosen equipment and design consideration will be arranged to develop the general arrangement. The arrangement of the equipment, tanks, and storages will have a direct effect to ships weight distribution and its stability. The layout can be seen in Figure 7 for 2-dimensional drawings. For 3-dimensional drawings are illustrated by Figure 8 and Figure 9.

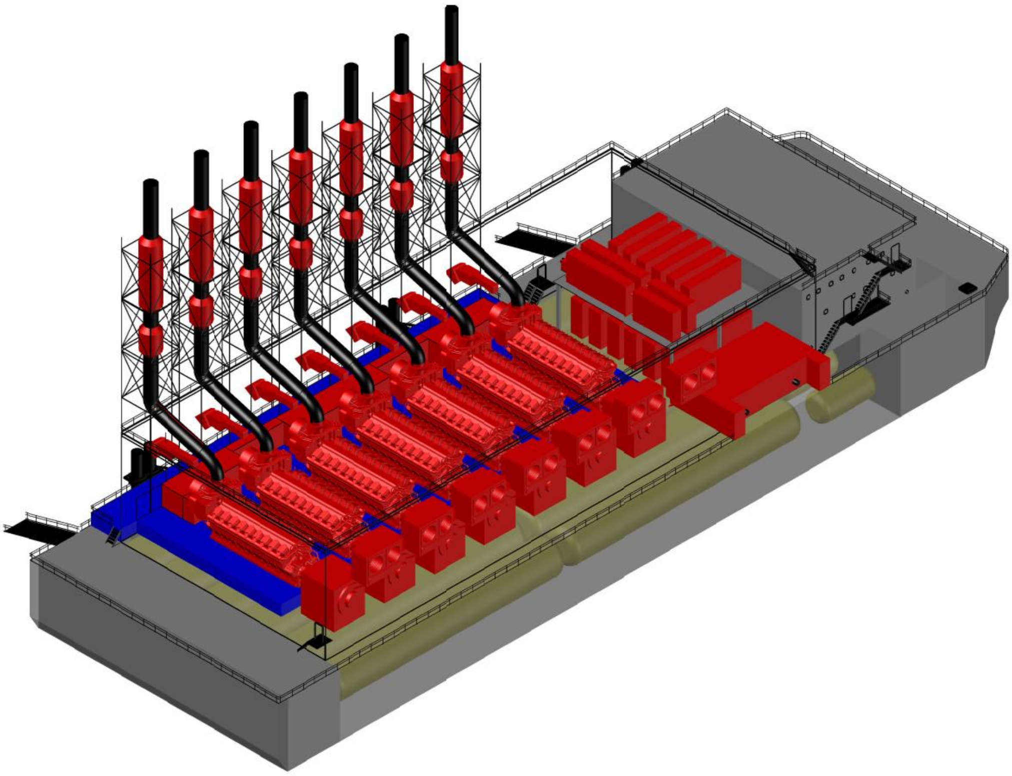

Figure. 8. 3-Dimensional general arrangement view 1

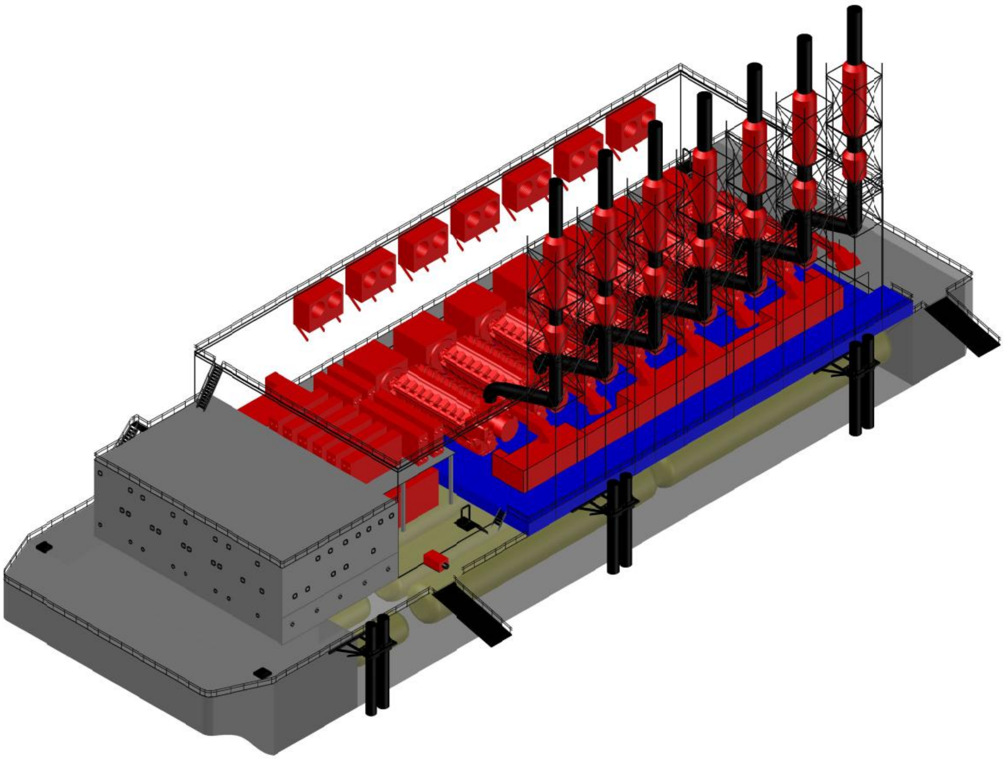

Figure. 9. 3-Dimensional general arrangement view 2

3.4 Stability, Buoyancy and Principle Dimension

The final principle dimension of the ship is 97.50 m for length, with breadth 32.20 m, draught at full load at 4.14 m. The design also has 11,825.4 m^3 volume displacement included with fixed ballast, 9,751.3 ton for its lightweight (LWT) and 2,160.5 for its deadweight (DWT)

The draught of the ship in lightweight condition with fixed ballast is 3.44 m with 0° of heeling and 0.23° trim to bow. This condition is the result of 10,062.8 ton of weight on board the barge. During fully loaded condition where deadweight, lightweight, and fixed ballast present, the draught of the floating barge power plant reach 4.14 m with 0° of heeling and 0.31° trim to bow. This condition is the result of 12,121.1 ton of weight.

The hydrostatic properties of the floating barge power plant calculations were done using empirical formula provided in Parametric Design Book [11] while the stability calculation were done using several formulas provided in Barge Stability Guidelines [12] and Basic Ship Theory book [13].

The stability result of the arrangement compliance with the regulations developed by IMO related with stability and hydrostatic properties are as;

- "The righting lever GZ is to be at least 0.20 m at an angle of heel equal to or greater than 30°" (IS Code 2008 A,2.2.2). The existing value of the design is 9.31 m. (Accepted)
- "The maximum righting arm is to occur at an angle of heel not less than 25°" (IS Code 2008 A,2.2.3). The existing conditions shows maximum righting arm is not occur at angle less than 25°. (Accepted).
- "The initial metacentric height GM0 is not to be less than 0.15 m." (IS Code 2008 A,2.2.3). The existing condition shows 15.14 m. (Accepted)
- "The validity of such damage stability calculation is restricted to an operational trim of ±0.5% of the ship's length L (0.49 m)." (MSC.Res216(82), Reg. 5-1.3, 7.2). The existing condition shows 0.31 m. (Accepted)

3.5 Operation

This sub-chapter mainly discussed about the operation duration capability of the plant to be operated during its full load and average daily load. The other operation that will be discussed is the method to supply LNG from the source into the ship where it may come from ship or truck.

Operation Duration

The current design and arrangement enables the power plant to be operated for 4.57 days when the load of the plant is 100 MW continuously. In the reality, it's not common to have 100 MW of load continuously since the behavior of the electricity consumer may vary by the time and their activity.

Based on the existing data the power plant may have fluctuated load, but it can be concluded that the average load for one day is at 64.78 MW by neglecting the change of the load. The operation duration when the power plant operated with 64.78 MW may reach 7.06 days. As a note, the calculation for daily average load done by using static load rate when the plant need to produce 64.78 MW while the change of the load rate which is the direct effect of load changes is neglected due to the availability of the data.

Bunkering

To have a continuous operation, the floating barge power plant need to be supplied with fuel periodically. In this case, the most essential fuel need to be discussed deeper is LNG bunkering. The current design for 100 MW Floating Barge Power Plant enables 2 methods of bunkering which is Truck-to-Ship (TTS) and Ship-to-Ship (STS) method.

Most of the operation of the plant can be supplied by the STS method since the capacity of the bunker ships are higher compared to the truck. The TTS bunkering method is used as supplementary supply for the plant or it can be considered to prolong the operation of the floating barge power plant.

Figure 10 shows the bunkering system process diagram where the left part shows the process diagram inside the bunker ship and the right part shows the process diagram in floating barge power plant. Every tank has a filling line and gas return line to enable bunkering operation without over-pressuring the tank due to the presence of boil off gas (BOG).

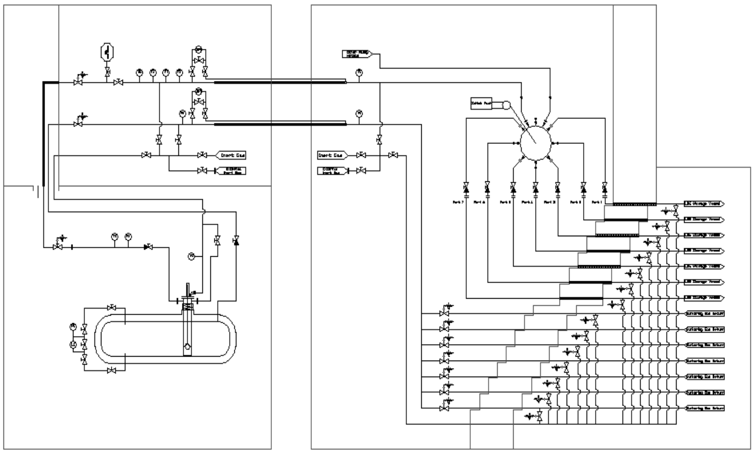

Figure. 10. Bunkering system

IV. CONCLUSION

Based on the calculation, design, and drawing process which has been done to develop *Design of 100 MW LNG Floating Barge Power Plant*, it can be concluded that the design is;

1. Using the selected machineries to power up the 100 MW LNG floating barge power plant which is 7 MAN 18V51/60 diesel engines with gas fuel consumption as main priority.
2. The 100 MW LNG floating barge power plant system design and arrangement were complied with Germanischer Lloyd regulations, engine manufacturer product guide, and several statutory rules related with ship design.
3. The 100 MW LNG floating barge power plant's stability and hydrostatic properties which calculated with empirical formulas provided by several references comply with the regulations from IMO.

REFERENCES

[1] Sekretariat Perusahaan PT PLN (Persero), "Statistik PLN 2014," Sekretariat Perusahaan PT PLN (Persero), Jakarta, Indonesia, 2014.

[2] IMO, Annex VI of MARPOL 73/78: Regulation for the Prevention of Air Pollution from Ships, London, UK: IMO, 2000.

[3] MAN Diesel & Turbo, MAN 51/60 DF Project Guide, Augsburg, Germany: MAN Diesel & Turbo SE , 2015.

[4] D. A. F. Muzhoffar, I. M. Ariana and W. Busse, "Technical Comparison of Propulsion System in LNG Carrier Boil-Off Gas Management," Jurnal Teknik ITS, vol. 4, 2015.

[5] Government of Alberta, "Energy Conversion," Alberta Energy, [Online]. Available: http://www.energy.alberta.ca/about_us/1132.asp. [Accessed 9 March 2017].

[6] International Gas Union (IGU), "Natural Gas Conversion Guide," dalam International Gas Union (IGU), Kuala Lumpur, Malaysia, 2012.

[7] Damen Shipyards Gorinchem, B32 Stan-pontoon Barge, Industrieterrein Avenglingen West, Netherlands, 2012.

[8] S. Egashira, "LNG Vaporizer for LNG Re-gasification Terminal," KOBELCO Technology Review, vol. 32, pp. 64-69, 2013.

[9] B. Eisentrout, S. Wintercorn dan B. Weber, "Study Focuses on six LNG Regasification Systems," LNG Journal, pp. 21-22, 2006.

[10] Lapesa Grupo Empresarial S.L., Technical Data Horizontal Tank, Zaragoza, Spain, 2016.

[11] M. G. Parson, Chapter 11: Parametric Design, Michigan: University of Michigan, 2001.

[12] Maritime New Zealand, Barge Stability Guidelines, New Zealand: Maritime New Zealand, 2006.

[13] E. C. T. J. K. Rawson, Basic Ship Theory, Oxford: Butterworth-Heinemann, 2001.

[14] M. Mukhtasor, T. B. Musriyadi, I. S. Arief, and A. W. C. Saputra, "Horizontal Pendulum Performance Analysis with Multilevel Model Plate on Ocean Wave Electric Power Plant (PLTGL)," *Int. J. Mar. Eng. Innov. Res.*, vol. 1, no. 2, Mar. 2017.